# The Climate Impact of Climate Simulations: a Simulation

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**As climate change increases the intensity of natural disasters, society needs better tools for adaptation. Climate simulations, for example, have been increasingly used to understand the impacts of a changing climate and identify the most effective actions for climate adaptation. Climate simulations, however, are often run on exascale supercomputers and, based on our analysis, a single climate simulation can emit up to 1400 metric tons of $CO_2$. Our work is the first to analyse how the emissions of climate simulations increase the need for climate simulations. We further propose the first model to simulate how more simulations cause more $CO_2$ emissions, leading to a climate simulation climate tipping point. As our simulation shows that increasing the number of climate simulations cannot be sustained, we recommend a paradigm shift towards a research climate of running fewer climate simulations[1].**

***Index Terms*—Climate, Simulations, Climate Simulations, Climate Tipping Point, Runaway Climate.**

## I. Introduction

Climate change is the defining challenge of our time [1].Society has been leveraging climate simulations to understand climate impacts and identify climate adaptation measures that minimize the societal, ecological, and economic damage of climate change [1]. Alarmingly, historical data in Fig. 1 reveals that the number of climate simulations has been exponentially increasing as a function of global $CO_2$ emissions. We presume as the economic impact of climate change increases over time [2], more climate simulations are needed to understand climate impacts.

We further calculate that a single climate simulation can consume up to 1400MWh, emitting approximately 1400 metric tons of $CO_2$; or the equivalent of 8 railcars' worth of coal burned [3]. The emissions of the increasing number of climate simulations suggests a feedback loop. We derive the first simulation of this feedback loop and predict that a tipping point will occur in $\sim 2035$.

Our work makes three key contributions:

- the first formulation of the impact of climate on the number of climate simulations,
- an updated formulation of the climate impact of climate simulations, and
- the first derivation of the *climate simulation climate tipping point* (CSC-TP)

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[1]Code and data will be open-sourced upon publication

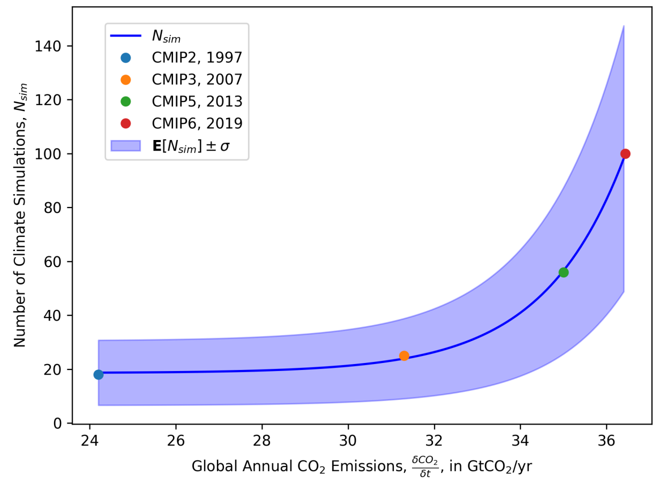


Fig. 1: **The impact of climate change on climate simulations function.** As climate change increases more climate models are run to help societies understand and adapt to the impacts of climate change. Data sources: CMIP2 [4], CMIP3 [5], CMIP5 [6], CMIP6 [7]

## II. Impact of Climate on Climate Simulations

We have observed that the amount of $CO_2$ emitted by the world per year has increased in recent years [1]. We have also observed that over time, the number of climate simulations run by climate scientists has increased at an increasing rate [4][5][6][7][8]. From these observations, we come to the only logical conclusion – as the amount of $CO_2$ emitted increases, scientists run more climate simulations. Figure 1 demonstrates this causation.

One possibility is that the increasing impact of climate change drives more scientists to the field, who then run climate simulations to understand the impact of increasing $CO_2$ emissions. Other explanations have been reasonably considered, however ascribing an underlying justification to this phenomenon is beyond the scope of this paper. For our purposes, we merely draw your attention to this impact of climate on climate simulations.

We leverage state-of-the-art machine learning-based algorithms [9] to learn the relationship between the number of climate simulations run yearly and annual $CO_2$ emissions. We call the functional form of this relationship the impact of climate on climate simulations (ICCS) such that

$$\mathrm{N_{sim}} = ICCS\left(\frac{\partial \mathrm{CO_2}}{\partial t}\right) \tag{1}$$

Where $CO_2$ represents the annual $CO_2$ emissions and $N_{sim}$ represents the number of simulations run in a given year.

## III. Climate Impact of Climate Simulations

It is an inescapable fact that running climate simulations costs energy, which generates additional $CO_2$ that is emitted into the atmosphere. In this section, we consider the $CO_2$ emissions generated by running a standard climate simulation.

The climate simulation we consider, henceforth the nominal simulation, is a recent weather model by the European Center for Modeling and Weather Forecasting (ECMWF) that resolves deep convection at 1km horizontal resolution [10][2]. The nominal climate simulation requires 500K node hours[3] on the Summit super computer at Oak Ridge National Labs which has 4608 nodes and consumes 13MW at peak performance[4] [10], [11].

The nominal simulation has an energy consumption of:

$$\frac{500,000 \text{ node-hours}}{1 \text{ simulation}} \times \frac{\text{Summit}}{4608 \text{ nodes}} \times \frac{13\text{MW}}{\text{Summit.}}$$

Which equals 1400 MWh of energy consumption for each climate simulation.

We then convert this into a quantity of $CO_2$ emissions as follows. The US Energy Information Administration quotes (in 2019) a $CO_2$ emission figure of 952 million metric tons per 947,891 million kWh of electricity generation [12][5]. This gives:

$$1400 \frac{MWh}{\text{Simulation}} \times \frac{952 \times 10^6 \text{ metric tons}}{947,891 \times 10^6 \text{ kWh}}$$

Which equals 1400 metric tons of $CO_2$ emitted per climate simulation. Scaling this in the obvious way based on the mass of Earth's atmosphere, taking into consideration absorption by the oceans and the biosphere, we calculate the climate impact of climate simulations ($CICS$) parameter.

$$CICS = 6.4 \times 10^{-8} \frac{\text{ppm } CO_2}{\text{Climate Simulation}} \quad (2)$$

## IV. The Climate Simulation Climate Tipping Point

In this section, we consider both the impact of climate on climate simulations and the climate impact of climate simulations simultaneously to simulate the *climate simulation climate tipping point* (CSC-TP).

We simulate the dynamical system consisting of the following system of dynamical equations. We call this model the Climate-Simulation Limitations Model (CLM).

$$\begin{aligned} \frac{\partial^2 CO_2}{\partial t^2} &= \frac{\partial^2 {CO_2}^{\text{nom}}}{\partial t^2} + CICS \frac{\partial N_{\text{sim}}}{\partial t} \\ N_{\text{sim}} &= ICCS\left(\frac{\partial CO_2}{\partial t}\right) \end{aligned} \quad (3)$$

Here, $CO_2$ represents the total amount of $CO_2$ in the atmosphere in ppm and $N_{\text{sim}}$ is the number of simulations run in a given year. $CICS$ is the climate impact of climate simulations parameter, derived in section III, and $ICCS$ is the impact of climate on climate simulations function as described in section II.

For this paper, we base the nominally predicted $CO_2$ emissions, $CO_2^{\text{nom}}$, on the RCP8.5 scenario [1]. Thus, this variation of our model will be referred to as the CLM-8.5 model, pronounced "climate point five".

To minimize the climate impact of CLM-8.5, we only allow it to run for a few years into the future. Our results are shown in figure 2, compared to the RCP8.5 scenario.

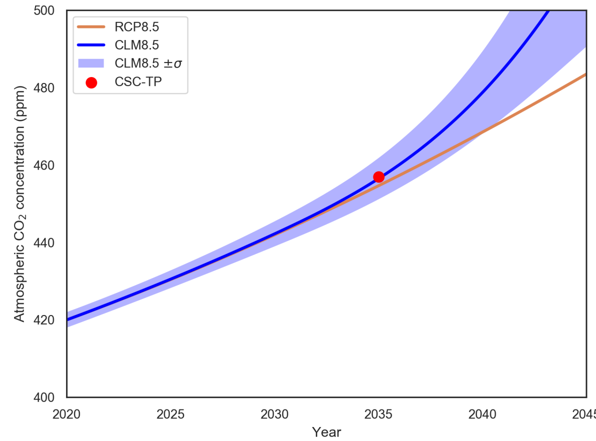


Fig. 2: **The climate simulation climate tippint point.** We simulated that the CO2 emissions of running more climate models to better understand climate change will cause the climate simulation climate tipping point (CSC-TP), causing a runaway climate by the year 2035.

The results are clear – if climate scientists continue to contribute to climate change by simulating the climate, we will reach a tipping point. As the climate worsens, scientists run more simulations to understand it, which in turn contributes to worsening the climate. This feedback loop culminates in the climate simulation climate tipping point (CSC-TP), where the atmospheric $CO_2$ concentration increases dramatically above the nominal value. We note the models begin to diverge in 2035, and mark that date as the CSC-TP.

## V. Discussion and Future Work

Future works will consider the climate impact of the climate simulation ran for "The Climate Impact of Climate Simulations: a Simulation". Additionally, future works will calculate the climate simulation budget, i.e., the maximum number of climate simulations until the CSC-TP is reached, to aid policymakers in the fair distribution of the remaining climate simulation computing time. Further, we encourage climate researchers to stimulate change towards a research climate that fosters a reduction in climate simulations.

## VI. Acknowledgement

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[2] Assuming weather and climate simulations are on the order of same computational complexity.

[3] Assuming the computing budget is needed to run a single climate simulation.

[4] Assuming the supercomputer runs on peak performance.

[5] Assuming all electricity is generated by coal

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